

Claims

- [c1] A method of estimating velocity ahead of a drill bit disposed in a subsurface formation, comprising:
generating seismic waves at a surface from at least two different source positions in the vicinity of a borehole traversing the formation;
receiving seismic waves reflected from a reflector ahead of the drill bit at one or more locations in the borehole;
determining travel times of the seismic waves received at the one or more locations; and
inverting the travel times to determine a velocity of the formation ahead of the drill bit.
- [c2] The method of claim 1, further comprising transforming the velocity into pore pressure of the formation.
- [c3] The method of claim 1, where the drill bit is substantially at the same depth for the different source positions.
- [c4] The method of claim 1, wherein the seismic waves are generated by at least one seismic source on the surface.
- [c5] The method of claim 1, wherein determining travel times of the seismic waves comprises determining arrival times of the seismic waves reflected from the reflector at the

one or more locations.

- [c6] The method of claim 5, wherein receiving seismic waves comprises detecting the seismic waves from at least one seismic receiver at a location in the borehole.
- [c7] The method of claim 6, wherein the seismic receiver is disposed in a downhole tool near the drill bit.
- [c8] The method of claim 5, wherein receiving seismic waves comprises sending a representation of the seismic waves to the surface via telemetry and processing the representation at the surface to determine the arrival times.
- [c9] The method of claim 5, wherein receiving seismic waves further comprises processing the seismic waves in the borehole to determine the arrival times and sending the arrival times to the surface via telemetry.
- [c10] A system for estimating velocity ahead of a drill bit disposed in a subsurface formation, comprising:
 - at least one seismic source on a surface for generating seismic waves from at least two different source positions in the vicinity of a borehole traversing the formation;
 - at least one seismic receiver in the borehole for detecting seismic waves reflected from a reflector ahead of the drill bit;

a telemetry system for transmitting data between the seismic receiver and the surface; and
at least one processor adapted to process instructions for determining velocities ahead of the drill bit using travel times of seismic waves reflected from the reflector.

- [c11] The method of claim 10, where the drill bit is substantially at the same depth for the different source positions.
- [c12] The system of claim 10, wherein the processor further comprises instructions for converting velocities to pore pressures ahead of the drill bit.
- [c13] The system of claim 10, further comprising a tool that determines arrival times of seismic waves detected by the seismic receiver.
- [c14] The system of claim 13, wherein the processor is further adapted to process instructions for determining the travel times from the arrival times.
- [c15] The system of claim 13, wherein the tool is located near the drill bit.
- [c16] The system of claim 10, wherein the seismic receiver is disposed on a drill string.

- [c17] The system of claim 10, further comprising at least one clock for synchronizing, generating, and detecting the seismic waves.
- [c18] A method of estimating velocity ahead of a drill bit disposed in a subsurface region, comprising:
obtaining surface seismic data for a region of interest;
during drilling of a borehole traversing the subsurface region, determining a travel time of a seismic wave generated from a surface of the region to a location in the borehole when the drill bit is at selected depths in the borehole;
determining a velocity from the travel time and the selected depths; and
inverting the surface seismic data to determine a velocity ahead of the drill bit while constraining velocity between the surface and the drill bit to be consistent with the velocity determined from the travel time.
- [c19] The method of claim 18, further comprising transforming the velocity ahead of the drill bit into pore pressure of a region ahead of the drill bit.
- [c20] The method of claim 18, wherein the seismic wave is generated by a seismic source positioned near an opening of the borehole.

- [c21] The method of claim 18, wherein determining the travel time of the seismic wave comprises detecting the seismic wave from at least one seismic receiver at a location in the borehole.
- [c22] The method of claim 21, wherein the seismic receiver is disposed in a downhole tool near the drill bit.
- [c23] The method of claim 21, wherein determining the travel time further comprises measuring the arrival time of the seismic wave detected at the seismic receiver and determining the travel time from the arrival time.
- [c24] The method of claim 23, wherein measuring the arrival time comprises sending the seismic wave detected in the borehole to the surface and processing the detected seismic wave at the surface to determine arrival time.
- [c25] The method of claim 23, wherein measuring the arrival time comprises processing the seismic wave detected in the borehole to determine the arrival time and sending the arrival time to the surface via telemetry.